ANALYSIS OF ENERGY SUPPLY SYSTEMS DECENTRALIZATION IN URBAN AREA

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ABSTRACT

In this paper analysis of energy supply systems decentralization was made. Energy supply of real urban area with heat and electricity depends on energy efficiency, investment and operational costs. At the beginning biogas plant, hot water and gas network planning are presented. Analysis consist of three examples: firstly, biogas plant generates electricity and distributes heat by hot water network; secondly, biogas plant distributes biogas to smaller cogeneration units inside of urban area; finally, produced biogas is burned in internal combustion engine and distributed to individual users boilers. On the basis of investment and operating costs, the calculation of cost prices of heat and electricity was made at the end.

POVZETEK

V tem prispevku je narejena analiza stopnje dislociranosti energetskih sistemov pri oskrbi realnega urbanega naselja s toplotno in električno energijo glede na energijski izkoristek, investicijske in obratovalne stroške. V začetku je predstavljen energetski sistem bioplinarne in načrtovanje vročevodnega ter plinovodnega omrežja iz kogeneracijskega postrojenja. Nato so narejeni trije primeri oskrbe: v prvem, bioplinarna proizvaja električno energijo in distribuira toploto po vročevodu; v drugem primeru bioplinarna distribuira bioplin do manjši kogeneracijskih postrojev znotraj naselja, in v zadnjem primeru, bioplinarna proizvaja bioplin za potrebe prigrajenega postroja in za kurjenje v individualnih kotlih. Na podlagi investicijskih in obratovalnih stroškov je na koncu narejen tudi izračun lastnih cen toplotne in električne energije.

1. INTRODUCTION

Due to rising energy demand in the world, amount of fossil fuels is rapidly decreasing. The phenomenon of reducing energy independence in some countries leads to political tacting and disordes. There is more and more tendency to utilize alternative energy sources, but we can not pass without a transitional period of the utilization of both, existing and renewable energy sources in cogeneration plants. For this purpose it is necessary to plan an optimal future energy systems in relation to: location and availability (time and energy) energy source, location of customers - consumers and the dynamics of consumption and operating experience to date with advanced technologies in the energy sector. Such planning will leads to decentralized energy systems involved in active network operating with radial configuration. Active network will connect the existing thermal systems and the individual self-sufficient energy islands. Individual energy island will be connected to base electricity network, primary energy sources and individual consumers of electricity and heat. Such concept of energy supply in urban areas will improve energy security; use of waste heat from energy systems and some industrial processes will also reduce the use of primary energy sources.

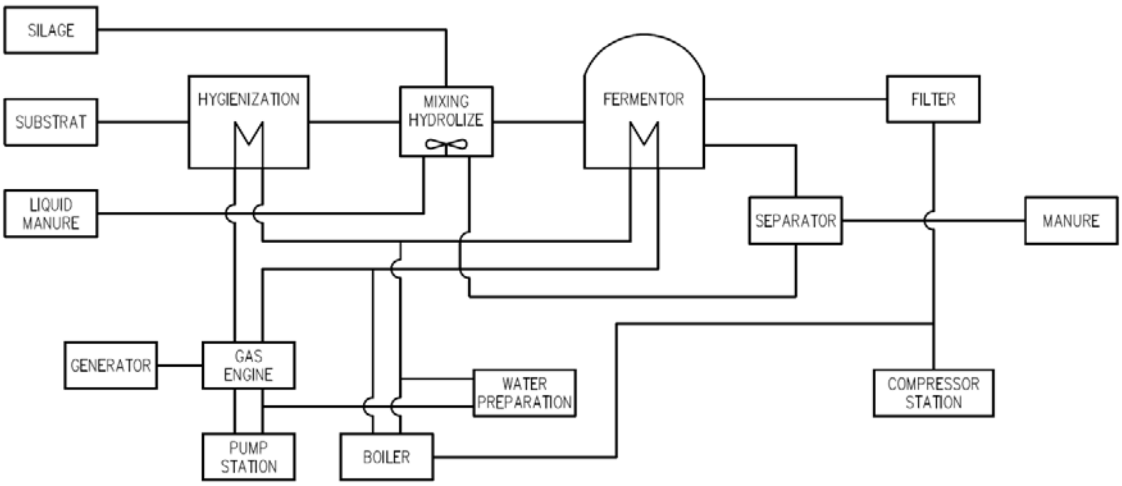
In this paper we analyze the various options of energy supply of the selected urban area, we consider modern technologies to convert primary energy sources in the final form of energy, safe and efficient energy supplies and also distribution of heat and secondary sources of energy to consumers. We analyse three different modes of supply of energy in real urban area, which urban development plan envisages the construction of hot water and eventually gas network. In the first case the gas engine of biogas plant produces electricity and distribute heat to consumers. In the second case, biogas from biogas plant is distribuited to smaller cogeneration units inside of urban area.

Picture 1: Urban area Kostanjevica na Krki

Finally, the last case presents production of biogas, that is used for electricity production with gas engine and is distribuited to individual gas consumers for heating. Each mode of supply of energy is evaluated in relation to energy efficiency, investment and operational costs. We design energy system, hot water and gas distribution network. At the end we calculate the cost prices of electricity and heat.

2. BIOGAS PLANT

Waste water, containing organic impurities, is suitable for anaerobic fermentation, especially suitable as industrial untreated water from the meat, dairy, pulp, leather, sugar industry, and water from agricultural farms and breweries. Waste water is adequately prepared and then starts the anaerobic process in fermentor. The transformation of waste water runs without the presence of air and under particular chemical - physical conditions in which methanogenic bacteria decompose organic matter and generate a mixture of biogas (55 - 75% CH_4, 25 - 45% CO_2 and 5 % H_2O and H_2S). The process of biogas generation depends on the chemical composition of organic matter, temperature regime, process timing and type of fermentor. Mostly used is the mesophilic process, which takes place at 25 - 45°C for about 20 days. Modern fermentor contains an inert granular material (1 - 3 mm), which improves circulation. The substrate is moved vertically; intensive contact of substrate and methanogenic bacteria results in a faster and more efficient anaerobic process.



Picture 2: Biogas plant scheme

For the purpose of maintaining constant temperature during the process, the space of fermentor is heated with special heat exchanger (a good coefficient of heat transfer and resistance to corrosion). The risk of fermentation course represent the inhibition substances (antibiotics, organic acids, disinfectants and various toxic substances), which prevent the development of methanogenic bacteria by their presence.

Picture 3: Fermentor

Biogas is released at the anaerobic process at pressure of 3.5 to 4 kPa in the form of bubbles from the surface of the substrate, taking with it dust, moisture and corrosive gas component. The level of purification depends on the type of further consumer. For the separation of suspended particulate matter dry and coarse-fine filter with metal fillings or ceramic fiber is used. Due to condensation the filters must be provided for the release. When biogas is used as fuel to power internal combustion engines, it is necessary to remove moisture. The proportion of hydrogen disulphide H_2S depends on the sulfur content in the waste water. Hydrogen disulphide forms sulfuric acid H_2SO_4 in the presence of moisture. This acid acts corrosive and shortens the life of the further consumer. The most appropriate method of cleaning has proven to be dry regenerative absorption columns on base of iron compounds. Carbon dioxide CO_2 is inert and does not affect the combustion. It is removed from the biogas to increase the methane proportion and consequently caloric value. One way of disposing is wet process, which operates on the principle of absorption in water.

Today, the market offers special internal combustion engines that are modified for combustion of biogas. These are usually middle-fast diesel engines with low compression ratio, equipped with spark plugs. They are distinguished by high efficiency (> 0,4), long lifetime (> 60,000 h) and effective production of electricity and heat.

Picture 4: Internal combustion engine

Transformation of gas engine mechanical energy is done by electricity generator. Internal combustion engine is usually connected to synchronous diesel generator with the following basic characteristics: a cylindrical design turbogenerator, with the rated 1500 rpm, number of poles pairs 2, escape factor of 1.1 and cos φ 0.9.

3. PLANNING OF HOT WATER NETWORK

Hot water network is planned by the thermal and hydraulic calculation. Also experimental data in the form of tables and graphs are useful. The most important characteristics are:

transferred heat flow, pipe diameter, medium speed and pressure loss in the individual sections. Heat loss of pair of pipes can be expressed as

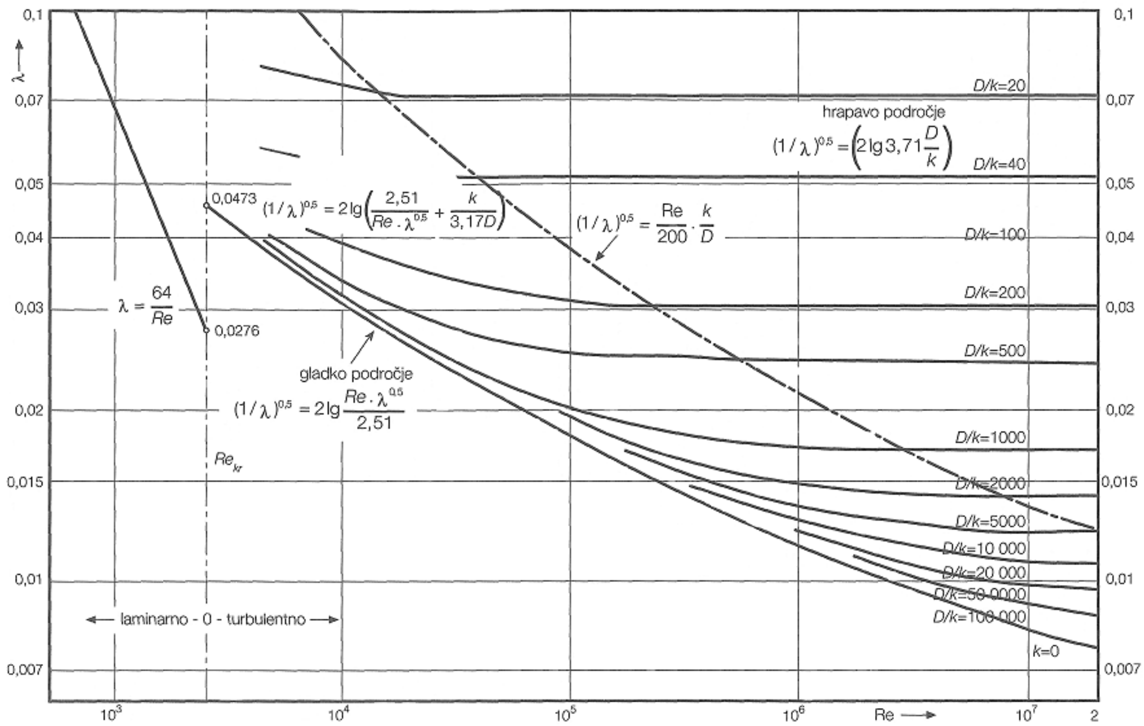
$$\dot{Q}_{loss} = U \cdot \left((t_{in} - t_{out}) - 2 \cdot t_{soil} \right)$$

When planning hot water network, next data are important: connecting power of consumers, the factor of simultaneity, the loss of network and system margin against the spread of hot water network

$$P = \sum (q \cdot s) + \dot{Q}_{loss} + P_{res} = \dot{Q}_v \cdot c_p \cdot \Delta T$$

Pressure drop in pipe can be calculated using the following formula

$$\Delta p = f \cdot \left(\frac{w^2}{2 \cdot g \cdot R} \right) \cdot L$$



Picture 5: Diagram showing influence of Reynolds number on friction factor

Relationship between faktor f and λ is equal to

$$\frac{1}{f} = \left(\frac{1}{\lambda} \right)^{0.5}$$

Friction factor *f* is determined for the intermediate area with the Colebrook-Whites equation

$$\sqrt{\frac{2}{f}} = 6{,}4 - 2{,}45 \cdot ln\left(\frac{k}{R} + \frac{4{,}7}{Re \cdot \sqrt{f}}\right)$$

Finally, the necessary power of pump station equals to

$$P_{\tilde{c}} = \frac{\rho \cdot \dot{V} \cdot g \cdot \Delta H}{\eta}$$

4. PLANNING OF GAS NETWORK

Gas network is planned by the hydraulic calculation and experimental data in the form of tables and graphs. The most important characteristics are: volume flow, starting and ending pressure pipe diameter and pressure loss in the individual section. Type of flow, laminar or turbulent, depends on the speed of flow, pipe diameter and fluid viscosity. It is identified by the Reynolds number

$$Re = \frac{Q_n \cdot \rho_n}{10^6 \cdot D \cdot \mu_n}$$

Friction factor λ (Darcy) or its reciprocal value $((1 / \lambda)^{0,5})$ is calculated by empirical formulas; one of them was written by Spitzglass

$$\left(\frac{1}{\lambda}\right)^{0,5} = \left[\frac{88{,}5}{1 + \frac{3{,}6}{D} + 0{,}3 \cdot D}\right]^{0,5}$$

When real gas flows through the pipeline, it does not behave like the ideal gas. Variety from the ideal gas depends on the characteristics of the gas drive pressure and temperature in the pipeline. Gas equation is written with a correction factor

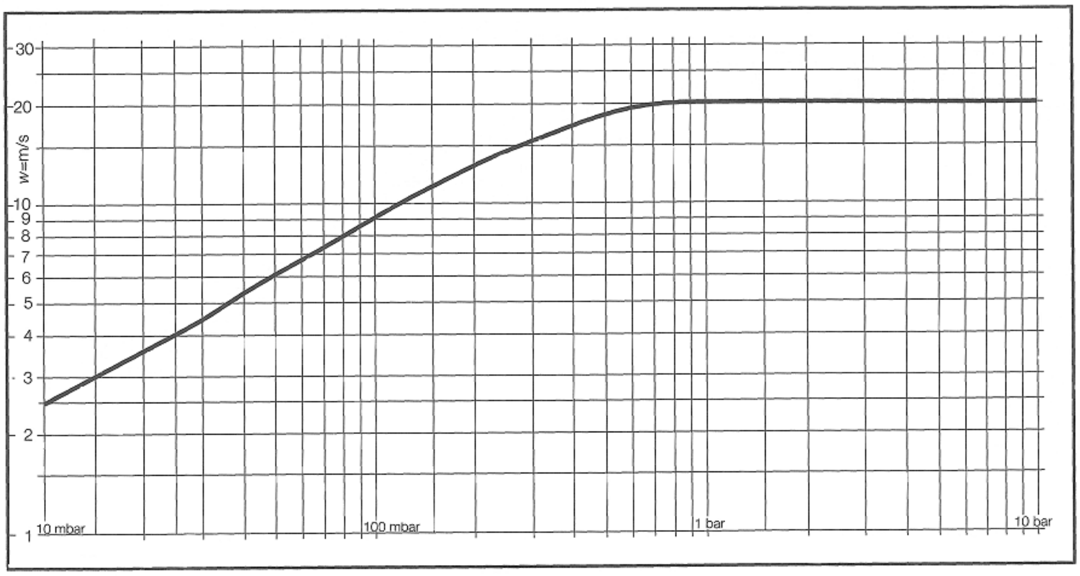
$$p \cdot V - Z \cdot R \cdot T$$

where *Z* is factor of compressibility (Berthelot)

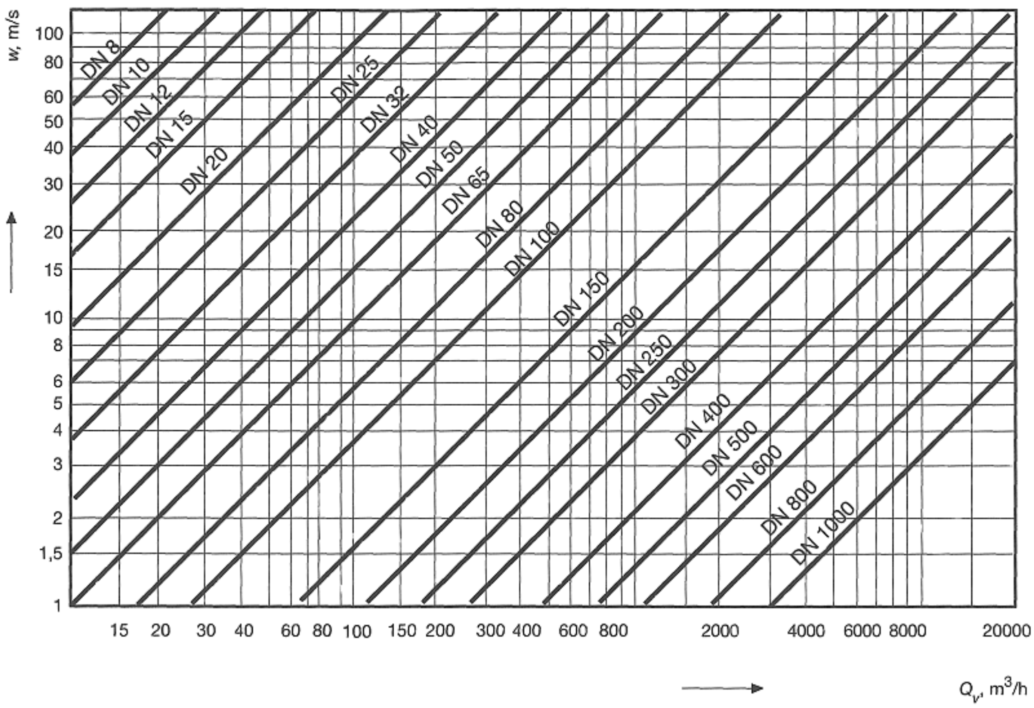
$$Z = 1 + \frac{9}{128} \cdot \frac{p_r}{T_{\infty}} \cdot \left(1 - \frac{6}{T_{\infty}^2}\right)$$

Combining the above equations and insertion of the constants gives final pressure drop equation

$$p_1^2 - p_2^2 = 1{,}71 \cdot 10^6 \cdot Z \cdot \lambda \cdot d \cdot Q_n^2 \cdot \frac{L}{D^5}$$



Picture 6: Diagram showing influence of pressure in pipe on gas speed



Picture 7: Diagram showing influence of volume flow on gas speed

A total pressure drop consists of a pressure drop in the straight section and of local pipeline elements

$$\Delta p = \xi \cdot \frac{w^2 \cdot \rho}{2} \cdot \left(\lambda \cdot \frac{L}{D} + \sum \xi\right)$$

Equation can be also written in next form

$$\Delta p = \frac{\lambda}{D} \cdot \frac{w^2 \cdot \rho}{2} \cdot (L + L_{eku})$$

The actual power of the compressor station is equal to

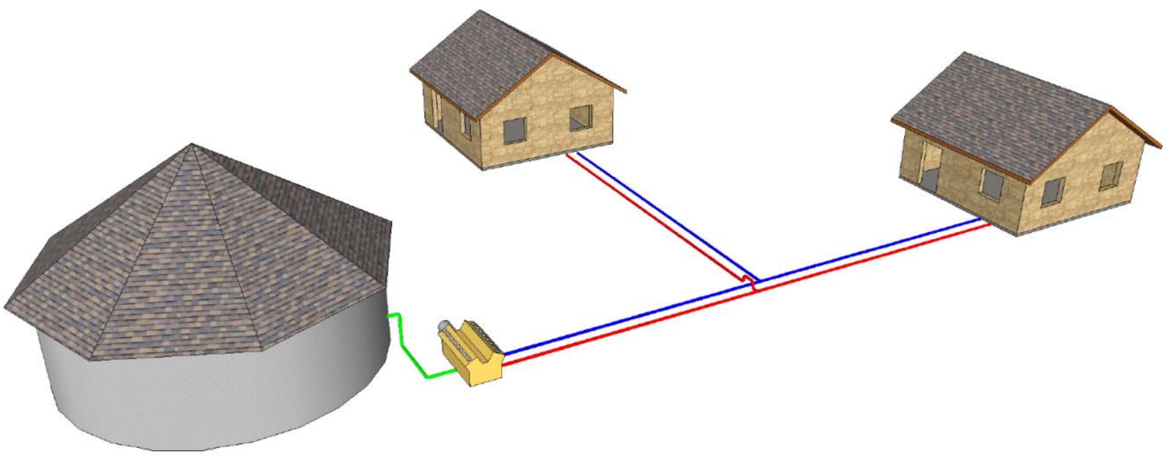
$$P_{comp} = \frac{\dot{m} \cdot \Delta p}{\eta \cdot \rho}$$

5. ENERGY SUPPLY SYSTEM MODELS

5.1 Biogas plant with production of electricity and heat

There are 69 facilities on the island with a total heating area 20.900 m^2 with an average heat consumption 60 W/m^2. In all three cases, the size of biogas plant and amount of produced biogas is equal (400 m^3/h of refined gas with methane proportion 0,95).

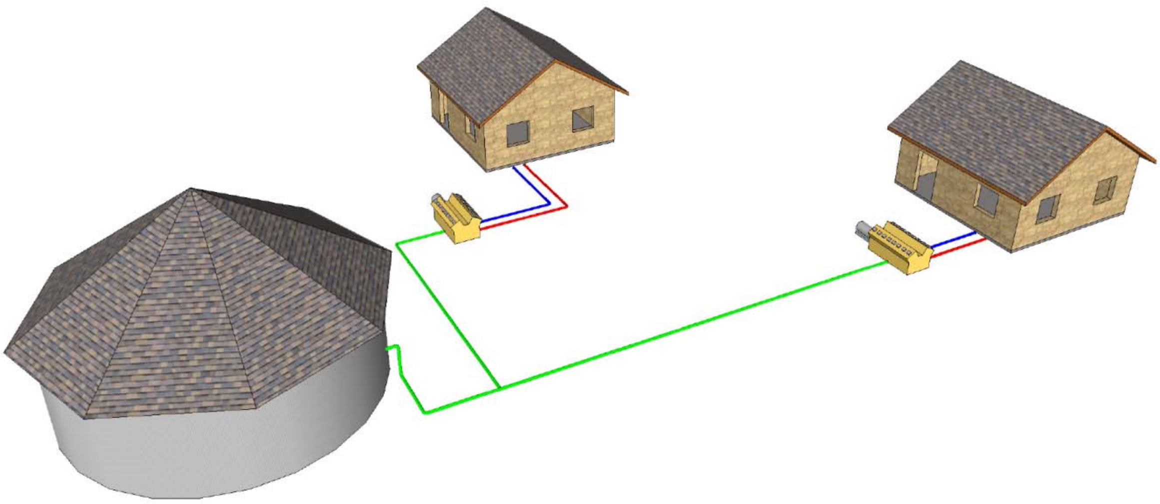
In the first case, we analyse energy supply of urban area by installing central cogeneration system, which produces with internal combustion engine electricity (1,5 MWe) and heat. Electricity is given to grid, whereas produced heat is distributed to individual users.



Picture 8: Biogas plant with production of electricity and heat

5.2 Biogas plant with smaller decentralized cogeneration units

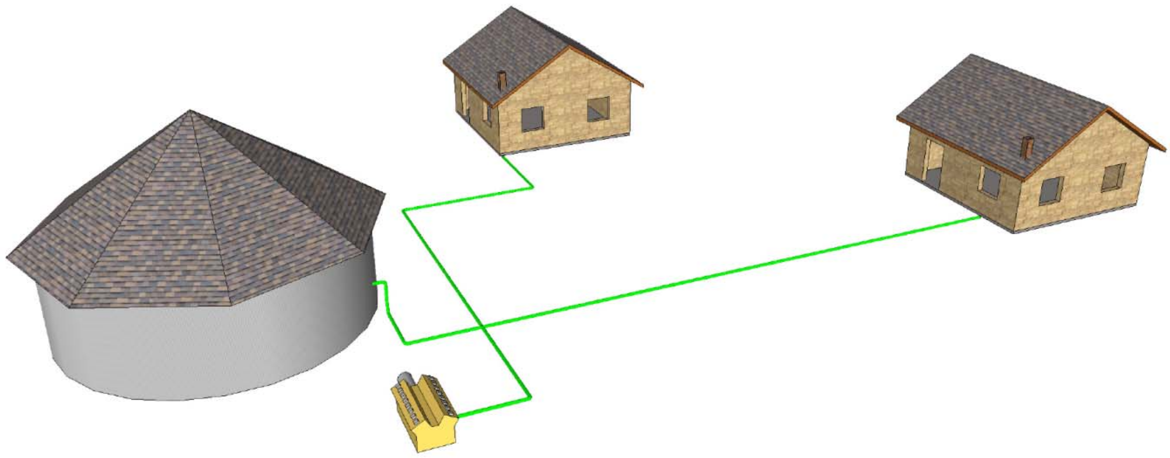
In second case, we analyse installing biogas plant, which produced biogas is burned in smaller cogeneration units installed inside of the urban area. They produce electricity (3x 0,35 + 1 x 0,3 MWe) and heat locally. Electricity production is at 1,35 MWe, which is slightly less than in the first case (1,5 MWe) becuase of installed 400 kW gas boiler in biogas plant for the technological needs. Electricity is given to grid, whereas produced heat is distributed to individual users.



Picture 9: Biogas plant with smaller decentralized cogeneration units

5.3 Biogas plant with production of electricity and biogas distribution

In the last case, we analyse installing biogas plant, which produced biogas is burned in central gas engine for electricity production (1,0 MWe) and distributed to individual consumers gas boilers.



Picture 10: Biogas plant with production of electricity and biogas production

6. COST PRICES CALCULATION OF ELECTRICITY AND HEAT

An energy cost price of each power plant depends on the fixed and moving costs, and quantity of produced electricity and heat. Fixed costs include investment costs, whereas moving costs include fuel (silage) and operating costs. Costs are divided on product of electricity and heat due to thermal efficiency and thermal plant number. Investment and operational costs of hot water and gas network are added to the price of heat.

Thermal plant number is defined as

$$\chi = \frac{\dot{Q}_H}{P_E}$$

Thermal efficiency of cogeneration system is

$$\eta_t = \frac{P_E}{\dot{Q}_{in}}$$

Ratio of electricity and heat specific cost price equalls to

$$\frac{c_E}{c_H} = \frac{1}{\eta_t} - \chi$$

	Unit	Model 1	Model 2	Model 3
Cost of biogas plant	€	7.700.000	7.937.000	7.650.000
Length of hot water network	m	1.780	1520	/
Cost of hot water network	€	316.800	214.900	/
Length of gas network	m	/	800	1780
Cost of gas network	€	/	51.200	123.300
Total investment costs	€	8.016.800	8.203.100	7.773.000
Urban area heat needs	MWh/a	2.915	2.915	2.915
Heat loss in hot water network	MWh/a	260	231	/
Total heat needs	MWh/a	3.175	3.146	2.915
Urban area gas needs	m^3/a	/	/	308.465
Operating time	h/a	8.700	8.700	8.700
Electricity production	MWh/a	13.050	11.745	8.700
Thermal plant number	/	0,243	0,267	0,335
Thermal efficiency	/	0,397	0,357	0,265
Ratio of specific costs (c_E/c_H)	/	2,276	2,532	3,445
Amortization time	years	15	15	15
Rate of interest	/	0,07	0,07	0,07
Annuity	/	0,11	0,11	0,11
Operating costs	€/a	1.514.000	1.620.000	1.490.000
Cost price of electricity	€/kW	0,163	0,192	0,244
Cost price of heat	€/kW	0,082	0,083	(0,075)
Cost price of gas	€/m^3	/	/	0,71

7. CONCLUSIONS

In this paper we discussed total energy supply of urban area. We studied energy system of biogas plant and planning of hot water and gas network to analyse three cases of energy supply and calculate the cost prices of electricity and heat.
The most important results can be summarized as follows:

- We would install biogas plant outside the island as an energy source, which would make use of liquid manure from the farms north of the town. Buildings on the island with its streets and squares are also a cultural heritage. District heating would be interested for keeping culture heritage due to unification of heating system. It would also be more orderly surroundings itself due to disappearance of store fuel (tanks for fuel oil and coal cellar), especially if these areas would be replaced by greenery. Roads and markets across the island with monuments have been already restored, this is why corridor of hot water or gas network should be on green surfaces with under road breakthroughs. This way of building networks achieves lower investment costs.

- Minimum prices for electricity and heat have been achieved in the case of installing central gas engine. Amount of produced electricity is the biggest due to the facts, that all biogas is firstly used for combustion in gas engine and it is not used directly for producing heat. The result is the minimum price of electricity and the second lowest one for thermal energy because of highest heat losses in the hot water network.

- Second lowest price of electricity is achieved in the case of installing central biogas plant and four smaller cogeneration units. By distribution of hot water we have less heat losses due to shorter distances and smaller diameters of pipes, but we have significantly higher investment costs at the expense of construction of the pipeline and installing a number of smaller cogeneration units. Smaller power plants have also higher operating costs. However, this system has an important advantage over others because the diversification provides greater security in the supply of energy. In case of failure of one of the plant, the rest three can partially assume heat demand in part of urban area, which at one, the central engine, that is not possible.

- The highest price of electricity is achieved in the third case, where smaller gas engine is installed. The rest of unburned biogas is distributed to gas consumers. The price is higher, because of separate production of electricity and heat, in spite of lowest investment and operational costs. But in this case, the lowest price of thermal energy (price of biogas) is achieved due to lowest investment costs for biogas plant and low prices for construction of the gas network.

8. LITERATURE

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